Rockburst Phenomenon
Data acquisition and analysis using multi-tasking and multi-user operating systems

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ABSTRACT:

In the last decade, CANMET has been, in conjunction with the Canadian mining industry and provincial agencies, involved in rockburst research projects. In order to fulfil its mandate, CANMET developed a remotely-controlled digital seismic data acquisition system which was designed in several versions: centralized, portable and intrinsically safe for coal mines environment. Concurrently, a powerful seismic waveform analysis software was developed.

The hybrid data acquisition hardware, which was designed and fabricated in house, utilises a multi-tasking multi-user UNIX™-like operating system, facilitating the data acquisition from Ontario and Québec mining operations. The system uses a robust high performance 32-bit real-time system, called QNX ™.

The data analysis is performed utilizing the software developed by the CANMET Rockburst Group. It was developed on a UNIX™-based operating system. Hence, the software is available for mini-computers and, now, for micro-computers running under SCO UNIX ™. An abridged version is also available under the QNX WINDOWS™ platform.

RÉSUMÉ:

Au cours de la dernière décennie, CANMET, en partenariat avec l'industrie minière canadienne et des gouvernements provinciaux, s'est impliqué activement au sein de programmes de recherche sur les coups de toit. Afin de remplir ses mandats, CANMET a développé un système d'acquisition de données séismiques digitales contrôlable à distance. Il est disponible en plusieurs versions: centralisé, portatif et adapté aux particularités des mines de charbon. Concurremment, un logiciel d'analyse des ondes séismiques a aussi été développé.

Ce système d'acquisition de données, conçu et fabriqué chez CANMET, emploie un système d'opération à tâches et à utilisateurs multiples, similaire au système UNIX ™. Ces dernières particularités facilitent l'acquisition des données dans plusieurs mines ontariennes et québécoises. Le système utilisé est appelé QNX™.

L'analyse des données est faite à partir du logiciel développé au sein du Groupe de recherche sur les coups de toit du CANMET. Initialement développé pour des systèmes d'opération UNIX ™, ce logiciel est maintenant disponible pour les micro-ordinateurs utilisant le SCO ™ UNIX. Une version abrégée est aussi disponible pour la plateforme QNX WINDOWS ™.

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INTRODUCTION

Mining induced seismic activity can have very serious, unfortunate and expensive consequences on mining operations and miners safety. Consequently, seismic monitoring equipment has been undoubtedly recognized as a key tool for rockburst hazard assessment and worker safety improvement.

Rockburst activity in Canadian mines increased significantly during the 1980's, specially in Ontario. A particularly active year was 1984, that culminated with the largest seismic event in modern Canadian mining history: a magnitude 4.0 event recorded at INCO's Creighton Mine in Sudbury. The high level of rockbursting raised concern from the industry. In response, the Canada-Ontario-Industry Rockburst Project was initiated in 1985 (Hedley & Udd, 1987). The objectives of this project were to develop state-of-the-art monitoring systems capable of capturing complete seismic waveforms and investigate the causes and mechanisms of rockbursts. The final output of this first phase was published in 1992 (Hedley, 1992).

Between 1990 and 1995, an expanded second phase of the Rockburst Project, the Canadian Rockburst Research Program (CRRP), was in progress. This second, five-year research project involves government agencies, universities and the Canadian & Chilean mining industries.

One of CANMET's contributions to the CRRP, through the Mining Research Laboratories (MRL), was the study of the mining induced seismic events located in the upper range of magnitude, i.e., magnitude 1.0 and above. To achieve this objective, a remote-controlled macroseismic system was developed which operates at a lower sampling rate and with the sensor grid being much wider than a microseismic system. Systems are now operating in three mines in northern Ontario, three in northwestern Québec and one in Nova Scotia. A menu-driven waveform analysis software was also developed in-house.

CANMET SEISMIC SYSTEM: AN OVERVIEW

CANMET has been one of the first pioneers in full seismic waveform monitoring in Canada. Involved since 1985, CANMET has designed a powerful, flexible and remotely accessible seismic system in order to fulfil the specific needs of the Canadian mining industry and for other research purposes. For specific applications, CANMET has also developed a portable unit based on the same technology. Furthermore, an intrinsically safe version of the same system has also been certified for coal mine environment (Talebi et al, 1995). This data acquisition system could be either autonomous or composed of electronic boards installed in commonly-used computers. All these systems are fully compatible and have beer proved very effective in numerous applications.

The CANMET Seismic System is a real-time, mine-wide, remotely-controlled state-of-the-art digital seismic data acquisition system. It is specifically designed to capture complete seismic waveforms in order to provide accurate event location and reliable magnitude as well as other seismic source parameters determination.

These systems are located at INCO's Creighton Mine at Sudbury, Placer Dome's Campbell Mine at Red Lake and Lac Mineral's Macassa Mine at Kirkland Lake. For the Québec mines, systems are located at Placer Dome's Sigma Mine and Cambior's Chimo Mine, both in Val d'Or, and Ressources MSV's Copper Rand Mine, in Chibougamau. An intrinsically-safe system is installed at the Phalen Colliery, in Sydney, Nova Scotia. They are mostly designed to capture the complete seismic waveforms to allow source location determination as well as seismic parameters. These systems also benefit the mine operators by allowing them to monitor the seismic activity originating from their mine. These in-house systems were commissioned between August 1990 (Strathcona Mine) and June 1995 (Copper Rand Mine).

The system software uses a robust high performance 32-bit real-time multitasking and multi-user QNX™ (QNX is a registered trademark of Quantum Software System Ltd) operating system. Fully "POSIX" (for Portable Operating System Interface) compatible, the QNX™ environment provides a familiar user interface for UNIX ™ (UNIX is a registered trademark of UNIX Systems Laboratories Inc.) users. Message passing between tasks allows the data acquisition process to be broken down into several small efficient modules to provide better real-time performance. This is especially important for systems running in continuous mode of operation.

The system reliability is also based on the acquisition hardware which has been designed with a "keep it simple" approach to reduce costs and

improve reliability. Historically, CANMET systems have been proved very efficient. Another main characteristic of the CANMET system is its flexibility. The system configuration allows a large selection of event size and duration for both near-field microseismic or far-field macroseismic works provided the sensor selection and locations are chosen accordingly.

Sensor gain, programmable if adequate wiring is provided, and triggering parameters allow the user to tailor the system to cover a wide range of magnitudes usually from -2.0 to +2.5 M_N. To record events above 2.5 M_N, the system may be supplied to operate in dual gain mode. The hardware is also designed to accept a wide variety of transducer types (accelerometers, velocity gauges and hydrophones).

The modular approach of the hardware design allows the system to be easily expanded from 16 to 64 channels simply by adding extra 16-channel triggering and A/D boards in the host computer. For systems larger than 32 channel, a 19-inch rack-mounted passive PC backplane should be used to provide enough slots to accommodate the extra boards.

Several systems can also be daisy-chained by connecting together the master trigger line from each system. If a system is triggered by an event, then all systems record simultaneously. This approach is used for networking portable systems to create large networks requiring a single pair of cable to access each unit. Furthermore, systems can be networked together since QNX™ provides full Ethernet capabilities.

System accessibility

As CANMET systems are located across the country, remote system accessibility is imperative to provide an adequate and prompt service. The QNX™ operating system, which includes a powerful communication package, provides easy access to remote sites and allows truly remote control system.

Most systems are connected via modems to CANMET's laboratories. At the mines, the data files can be edited and transferred to Sudbury or Val d'Or or some functions of the trigger controller can be altered.

Whether the system is a portable underground unit or a permanent system on surface, remote access is available using either a single leased line pair or a conventional dial up phone link. In both cases the operating system handles the remote logging process provided a modem is attached to the system.

Most CANMET acquisition programs have been developed to work using terminal functions for remote operation. Only programs such as waveform analysis and waveform display utilities cannot be run remotely since they operate in graphics mode. However, event files can be easily transferred without interrupting the acquisition for subsequent analysis on the remote computer.

Events can be simulated remotely to check the operation of the system. A detailed event log file is also available to review the system activity over time.

DATA ACQUISITION SYSTEM

Traditionally, high speed data acquisition was only possible using expensive, high powerful computers. However, with the technological advances made by the computer industry, it is now more cost-effective to use microcomputers to perform this task. Although high speed data acquisition hardware is now available, most software packages available operate under the operating system DOS, which lacks the flexibility and power of multi-tasking operating systems. This dictated the use of another system providing this convenience. Hence, CANMET opted for the QNX™ operating system. This allows the data acquisition system to be made up of several smaller tasks, which can run concurrently on a priority basis. Tasks not requiring immediate processing can be put on hold and not compete for processor time. Remote access to the system is also possible, simply by having a communication task run in the background, which requires minimal processor time.

Hardware requirement

The hardware is designed to operate on any 386 family or faster PC compatible computer. However, the recommended computer hardware requirements are: a CPU like a 486DX2 66 MHz, with a hard drive capacity of 500 Mb and a minimum memory of 8 Mb. Optional printer and 14400 or 28800 baud modem could also be added.

Triggering mechanism

One of the most unique features of the CANMET

data acquisition system is its triggering mechanism. Designed and developed in house, the mechanism is based on a triggering window which is initiated by any channel hit by a signal exceeding the minimum triggering level specified in the system configuration. Once the window has elapsed, the number of channels hit is then compared to the minimum number of channels required for a valid trigger. If both requirements are met the event is then recorded.

A sophisticated triggering controller has also been developed to eliminate the recording of very small seismic events, machine noise or electrical spikes which could saturate the system. The controller has the following software programmable features: selectable triggering levels, selectable pretrigger, trigger and event windows, selectable acquisition modes, selectable sampling rates, selectable number of channels for a valid trigger, automatic event screening, short-term integration for spike suppression, selectable trigger threshold, individual channel enable/disable switches, event simulation capability, input conditioner gain and dual gain sensor amplifier, and anti-aliasing low-pass filters. If the trigger controller determines that a valid event has occurred, then two seconds of seismic data are stored for each channel, including half a second of pre-trigger data. Except for the Creighton Mine and Sigma Mine systems, the acquisition is interrupted for about 200 milliseconds while the data are downloaded to the hard disk.

Data acquisition software

The acquisition software runs under QNX ™ version 4.21 (32 bit multitasking/multiuser) and is entirely written in C language. Although it may be run within the QNX WINDOWS™ environment (QNX WINDOWS™ Graphical User Interface, registered trademark of Quantum Software System Ltd.), it has been designed to run as a stand-alone application for portability and use in embedded systems, as in the portable version. The complete package consists of several program modules shown on Figure 1.

The primary acquisition program (DAC) is the heart of the system. It performs all initializations and starts up the other three modules (DAC_SON, DEMUX and LOCATE) to activate acquisition. It is then responsible for detecting, storing and queuing events in memory.

The secondary acquisition program (DAC_SON) is called by DAC to store events from memory to disk once they are acquired. The demux task (DEMUX) is then called to read the raw data from disk and reformat them with a proper header file so they can be read and displayed on screen by the analysis software (SEI-CAN) or by the display utility (DISP). The locate module (LOCATE), used during the demultiplexing process, provides a real-time automatic arrival time picking for source location calculation and magnitude value determination of the event.

The utility software (DAC_CONFIG) allows the user to set up all acquisition hardware and software parameters for the specific needs of his application. Configuration is performed either in operator mode or engineering mode. Operator mode is used to set the sensitivity of the system by changing the trigger level and the number of trigger channels to record an event. Engineering mode has password access and is used when commissioning the system to set system specific parameters such as sampling rate, event size and duration, pretrigger, trigger window, acquisition mode, anti-aliasing filters and other parameters including sensor coordinates and sensitivity factors. The acquisition parameters are set by the user via an intelligent menu-driven program which alerts the user for incompatible parameter selection.

Five last modules are secondary and are used for maintenance and troubleshooting purposes: an event simulator (SIMUL), a main menu executive (USER_EXEC), an audio monitoring utility (MONITOR), a basic troubleshooting display utility (DISP), and a packing and archiving utility (ARCHIVER).

The QNX™ operating system

The seismic system uses several operating system resources to provide powerful system maintenance tools.

Remote system access relies entirely on system commands to handle modem link-up, login procedures, file transfers and scheduling. The multitasking environment allows those tasks to occur without interrupting the data acquisition.

The following commands are the most important ones the system used.

The "modem" command monitors and controls all modem related functions. It is normally installed at boot time in the system initialization process and remain active at all times. "Qtalk" allows

communication and terminal emulation via a modem and is used as required by the user to initiate a link-up to a remote system (could be a DOS machine). "Qcp" provides efficient file transfer protocol. It is a QNX™ specific file transfer protocol but the popular X-Y-ZMODEM, from the DOS environment, is also supported.

The "ditto" command is quite interesting since it allows a remote user to literally take over control of a system console (virtual screen with associated keyboard). This feature allows the remote user to perform any task as if he was at the other location such as system parameter configuration, data acquisition control, including booting the remote machine. Only programs such as waveform analysis (SEI-CAN) and waveform display utilities (DISP) cannot be run remotely since they operate in graphics mode. This command is also particularly convenient to check the status of the data acquisition system as well as the summary of the recorded activity which includes the data acquisition parameter settings, the date and time of the recorded events, their location, magnitude value and more. This information is displayed on the main console while the data acquisition programs are being executed.

The "cron" command provides a convenient method for executing commands at specific times without operator intervention. It requires that the timer administrator be running in background.

The system also provides an automatic bootable process which initialises all data acquisition functions after any power failure. Furthermore, it provides a password system which can prevent the files from being tampered with by inexperienced users.

DATA ANALYSIS

Automatic location and magnitude determination

The CANMET Seismic System provides on site real-time automatic source location and magnitude determination for seismic events. Source location determination is based on Dr. Maochen Ge's algorithm which represents years of research and testing. Dr. Ge's technique has been implemented in several mines across Canada and the USA and is now well recognized internationally. It has been proven to be the most sophisticated and powerful algorithm in that regard as indicated in a study sponsored by the Mining Research Directorate (MRD) and carried out by Bharti Engineering Associates Inc (1993).

In addition to the event coordinates, several quality factors related to the accuracy and the reliability of the given source location are also provided. These factors include residual, sensitivity and event rank. The event residual is a total effect of mismatch between the observed and calculated arrival times, which is the most important criterion to measure the source location accuracy. Sensitivity measures the stability of the solution which is defined as the distance between a located source and its associated position obtained by assuming 10% lower velocity. For both parameters a lower value indicates a better solution. The rank, which is a combination of these quality factors, take also into account the hit sequence. This quality factor, which cannot be displayed on screen, compares the observed and calculated hit sequences and determines the seriousness of the mismatch. The rank is categorized into five classes (A,B,C,D,Z) where A indicates a very good rating, while Z means that the event is impossible to locate.

The magnitude calculation is based on the seismic energy integration recorded from the triaxial sensors. The calculated value is corrected for distance and then converted to an empirical Nuttli magnitude scale. For systems without triaxial transducers, seismic energy corrected for distance is provided.

CANMET Seismic Waveform Analysis Software

Since 1986, CANMET has developed a very powerful software for seismic waveform analysis. Source location, magnitude determination and seismic source parameter calculations of mining-induced seismic events are among the main features. The software, which includes many other options and research tools, is menu-driven and user friendly. For seismic systems installed at the mine site, an abridged version of the CANMET seismic waveform analysis software is also available.

Attempts has been made to include all those above parameters essential to rockburst engineers. Seismic waveforms can be displayed in acceleration, velocity or displacement mode. In addition to the focal mechanism analysis, the spectral analysis can also be done both in time or frequency domains. All seismic parameters such as seismic energy and equivalent Nuttli (1973)

magnitude values, peak particle velocity, acceleration and displacement to assess damage, corner frequency, seismic moment, stress drop, and others, are calculated and stored in a parameter file which can be printed and included in a report.

Other features, such as rotation of components, polarization analysis, determination of attenuation factor (Q), and many more are also available. Currently, new additions to the software is being developed which include surface and mined zone effects, raypath analysis, non-double-couple focal mechanisms and near-field/far-field analysis. This is a on-going development and the incorporation of new ideas is provided to the users on a continuous basis.

In order to run the entire CANMET seismic waveform analysis software without overloading the data acquisition system, a secondary computer is recommended. So far, the software has been successfully implemented on several mini-computers, all running under UNIX ™ WINDOWS System V operating system. Furthermore, the same software is now accessible for micro-computers, such as 386 or 486 computers, running SCO ™ UNIX WINDOWS System V operating system (SCO is a registered trademark of the Santa Cruz Operation Inc.).

QNX™ Waveform Analysis version

As a part of the data acquisition package, an abridged version of CANMET seismic waveform analysis software (SEI-CAN) is also available for QNX™ platform. Working in a WINDOWS environment, the software is menu-driven and easy to use. Furthermore, it can be run by mine personnel at the mine site.

Among the main features, the software allows waveform display, manual arrival time picking, source location optimization, seismic parameter determination, magnitude, seismic energy and peak particle calculations, etc. It also provides menu selection for event distribution as a function of time and magnitude values.

According to the data acquisition computer configuration, it could be recommended to run SEI-CAN on another computer.

CONCLUSION

Mining Research Laboratories of CANMET's involvement with the rockburst research in Canada, first in the phase I (COIRRP) and later as a partner in the Canadian Rockburst Research Program has contributed to the better understanding of the problems in rockburst engineering.

These efforts and endeavour, augmented by the financial contribu tion from the industry, the provincial government and their agencies, and the research efforts from the Canadian institutions of learning have brought the Canadian mining industry to the edge of the state-of-the-art of rockburst technology. Today, it could be claimed that the Canadian mining industry, after a quantum leap since 1984, has become one of the leaders in the forefront of rockburst research in the world.

One of these achievements, the CANMET Seismic System, has been designed to meet the needs of a wide range of applications in mining and other engineering situations, although using commonly-used computers. The knowledge acquired by CANMET, since 1985, through the rockburst research and the development of seismic monitoring equipments have contributed to create a centre of expertise that is available to the mining companies and other organisations concerned with rockmass stability.

CANMET can provide expertise for seismic activity evaluation, sensor selection, sensor array geometry optimization and system requirements. Individual system components or custom software and hardware development is also available for special applications. Other services may include system installation, calibration, training and data analysis.

Both the Val d'Or and Sudbury laboratories have active seismology groups working in rockburst and seismic research. Other activities include seismic tomographic imaging, source location software implementation, etc. Our facilities remain accessible to people who wishes to get a first hand look at our activities and seismic monitoring systems. Accessibility to seismic data from different mines can be most beneficial to our research so partnerships or other forms of collaborative projects mutually profitable are welcome.

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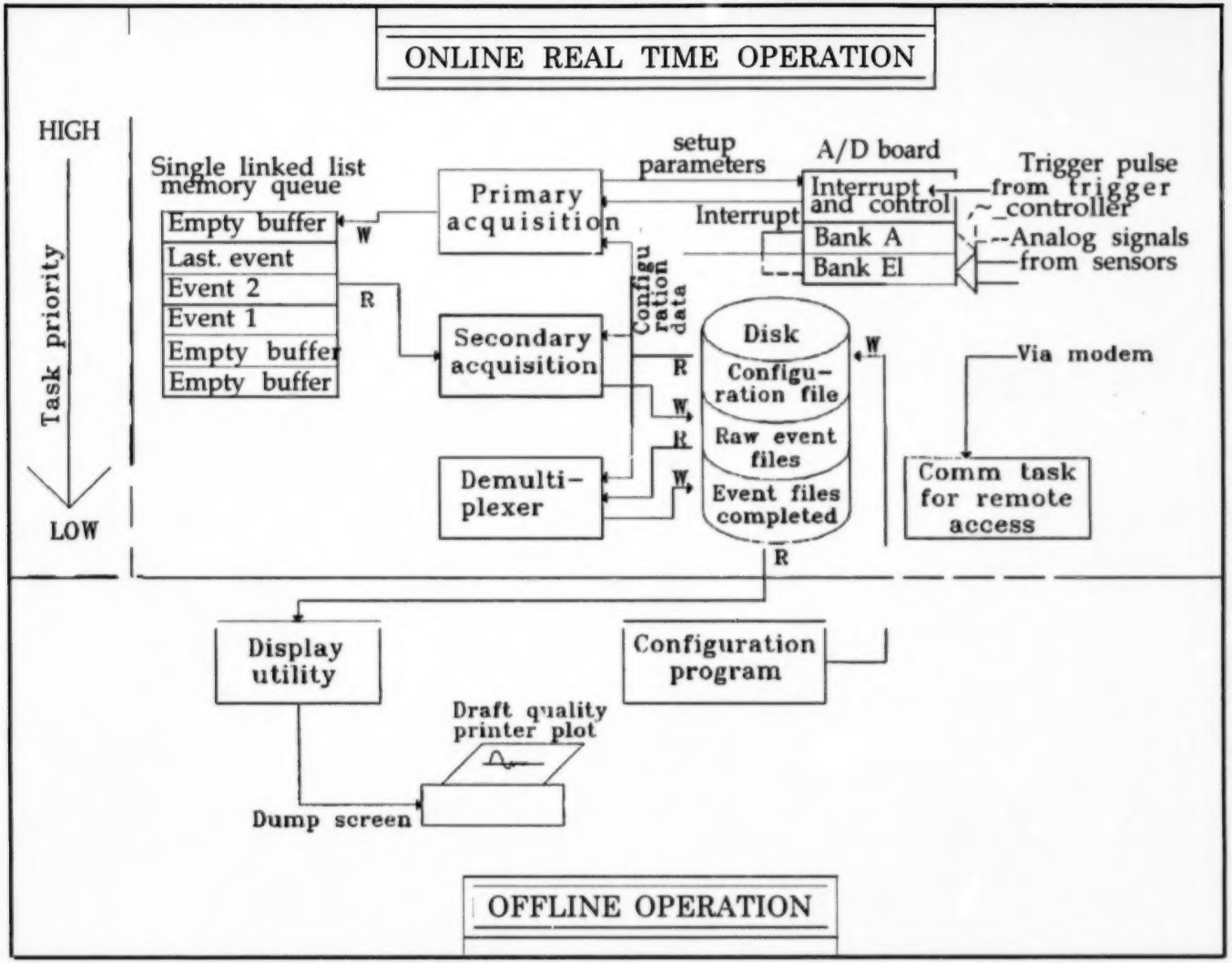

Figures

Figure 1. Flow chart of the data acquisition system used by CANMET'S seismic networks